



VEHICLE CONTACT WITH RADIOACTIVE DUST CLOUDS IN A NUCLEAR STRIKE REGION

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ABSTRACT

In the event of a nuclear attack, it is possible that the United States would be interested in sending air vehicles into, or near, the region affected by the nuclear strike. The radioactive dust clouds produced by the explosions could have a detrimental effect on any vehicle passing through them. This paper examines the likelihood of an air vehicle contacting a radioactive dust cloud as it passes in, or near, a region where nuclear explosions have occurred. An equation is derived to calculate the probability of entering a cloud, in a two dimensional space, in order to inform decision makers regarding the risk to air vehicles as they pass through nuclear clouds.

Vehicle Contact with Radioactive Dust Clouds in a Nuclear Strike Region

Problem

While the likelihood of nuclear war has decreased since the end of the Cold War, the use of nuclear weapons continues to be a possibility. If a nuclear attack occurs, whether inside the US or in a foreign country, the US may have a need to send aircraft into, or near, the radioactive dust clouds generated by nuclear detonations. The probability of an air vehicle entering a dust cloud is required in order to effectively plan the acquisition and operation of vehicles in a region where a nuclear strike has occurred.

This paper establishes the basic equations used to calculate the probability of an air vehicle encountering a radioactive dust cloud in a region of interest. The calculated probability is small, then additional precautions may not be needed to reduce the risk to the air vehicle. However, if the probability of intersection is significant, further research may be required to predict the location of radioactive dust clouds in order to plot courses around them. Additionally, the significance of the probability of intersection may influence the radioactive hardening of the air vehicle, or other design features. The region of interest is an area, at the altitude of the vehicle, within which all nuclear dust clouds are contained. The equations derived to calculate the probability of encountering a cloud are then used in a theoretical example to demonstrate their use for analytical purposes.

Discussion

Probability of intersection in a static environment

The probability of intersection, P_i , is the likelihood that the vehicle will enter a radioactive dust cloud of known area, while the vehicle is inside the region of interest. To find the general equation for P_i , the first step was to examine the least complex scenario: the probability of the vehicle being in a cloud at a single point in time. Assuming the area of the region of interest and the area of the cloud are known at the altitude of the vehicle, the probability of an air vehicle being inside the cloud is

$$P_i = \frac{C}{A_I} \quad (1)$$

Where C is the area of the cloud, and A_I is the area of the region of interest. Therefore, if an air vehicle enters a 10 square mile (sq mi) region of interest and a radioactive cloud has an area of 0.5 sq mi (at the vehicle's altitude), then the probability of the vehicle being in the cloud at any given time is 0.05, or there is a 5% chance that the vehicle is in the cloud.

If the vehicle enters a region where multiple radioactive clouds are located, a modification to Equation (1) is required in order to account for the increased number of clouds in

the region. Assuming the clouds do not overlap, the probability of the vehicle being in a cloud would simply be the summation of the areas of the clouds divided by the area of the region of interest:

$$P_i = \frac{C_1 + C_2 + \cdots + C_n}{A_I} \quad (2)$$

Where n is the number of clouds in the region of interest.

The assumption of non-overlapping clouds is one that may not be realistic in a real world situation. In order to calculate the probability of intersection with overlapping clouds, data is needed regarding the area of overlap between each pair of clouds, C_{jk} ; $j, k = 1, 2, \dots, n$. The equation for P_i then becomes

$$P_i = \frac{\sum_{j=1}^n C_j - \sum_{j=1}^{n-1} \sum_{k=j+1}^n C_{jk}}{A_I} \quad (3)$$

Note that Equation (3) does not account for more than two clouds overlapping at any given point. While the equations used to calculate P_i for multiple overlapping clouds could be derived, they are not within the scope of this paper.

Probability of intersection in a dynamic environment

While the previous section derived the equations for dust cloud intersection at a single point in time, this section examines the problem of calculating the probability of intersection as an air vehicle travels through a region with multiple, dynamic radioactive dust clouds. The assumption for traversing the region is that the size (area) of each cloud is known, while the location of them is not (if their locations were known, a course could be plotted around them and P_i would drop to 0!). Thus, if the clouds are distributed uniformly throughout the region of interest, an air vehicle is as likely to encounter a cloud immediately upon entering the region of interest as it is the moment before it leaves the region or at any time in between. If the area of the clouds is dynamic, then the probability of intersecting a cloud by a certain time, t , can be expressed as

$$P_i(t_e, t_d) = \frac{1}{A_I} \int_{t_e}^{t_d} \left(\sum_{j=1}^n C_j(t) - \sum_{j=1}^{n-1} \sum_{k=j+1}^n C_{jk}(t) \right) dt \quad 0 \leq t_e < t_d \quad (4)$$

Assuming the radioactive cloud stabilizes at $t = 0$, t_e is the time at which the vehicle enters the region of interest and t_d is the time at which the vehicle departs the region of interest. It is important to ensure that the areas for the radioactive clouds used in Equation (4) are completely within the region of interest until the vehicle leaves the region at time t_d , otherwise, inaccuracies will be induced into $P_i(t_e, t_d)$.

Example Problem and Solution

With the establishment of Equation (4) in the previous section, a hypothetical problem is solved to show how the equation could be used for risk assessment purposes. For this exercise the information in Table 1 will be used to find the probability of an air vehicle intersecting a radioactive dust cloud, $P_i(t_e, t_d)$.

Table 1: Example inputs for calculating cloud intersection probability

$A_I =$	500
$C_1(t) =$	$10t$
$C_2(t) =$	$3t^2$
$C_3(t) =$	$8t$
$C_4(t) =$	$6t^2$
$C_{12}(t) =$	$2t$
$C_{13}(t) =$	0
$C_{14}(t) =$	0
$C_{23}(t) =$	0
$C_{24}(t) =$	0
$C_{34}(t) =$	$0.5t^2$
$t_1 =$	1
$t_2 =$	3

If an air vehicle enters the region of interest at the time of cloud stabilization, $t = 0$, and departs the region at time t_2 , the probability of intersection, $P_i(0, t_2)$, can be found by using Equation (4).

$$P_i(0,3) = \frac{1}{500} \int_0^3 (10t + 3t^2 + 8t + 6t^2 - 2t - 0.5t^2) dt = \frac{148.5}{500} = 0.297$$

Thus, if an air vehicle enters the region of interest at, or before, the time of cloud stabilization and leaves at three time units after detonation, there is a 29.7% chance that the vehicle will enter a radioactive dust cloud before it leaves the region.

By comparison, if an air vehicle enters the region at t_1 and leaves at t_2 , then, using Equation (4), $P_i(t_1, t_2)$ becomes

$$P_i(1,3) = \frac{1}{500} \int_1^3 (10t + 3t^2 + 8t + 6t^2 - 2t - 0.5t^2) dt = \frac{137.667}{500} = 0.275$$

Therefore, an air vehicle which enters the region of interest at time $t = 1$ and leaves at time $t = 3$ has a smaller likelihood of encountering a radioactive cloud than one entering at the time of detonation, 27.5% versus 29.7%.

From these examples, it can be seen that the more time an air vehicle dwells in a region with radioactive clouds, the higher the probability that the vehicle will encounter a cloud. This is

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a logical result since the clouds get larger with time, thus the “safe” areas shrink, and the vehicle is in a region with radioactive clouds for a longer period of time. Note that only the probability of encountering a cloud is considered; nothing can be determined about the intensity of the radiation, the dust density, or other factors that could affect vehicle performance should contact with a cloud occur.

Summary

In order for the discussed equations to be accurate, certain attributes must be known. The known attributes are the area of the region of interest, the area of each cloud, the area of overlap between clouds, and the amount of time the vehicle will be in the region. These equations assume that the entire area of each cloud is contained within the region of interest, the dust clouds are distributed randomly within the region, and no effort is made by the vehicle to avoid clouds. Additionally, this method only applies for vehicles flying within the region of interest. No assumptions can be made about vehicle exposure outside the region.

The equations derived in this paper are useful in modeling air vehicle movement through a region in which a nuclear strike has occurred. While the equations assume that the clouds are randomly distributed across the region, future research could be performed to include calculations for other distributions which would be better representations in certain scenarios. Additionally, research into the time after detonation an air vehicle encounters a cloud could generate useful information for the cost/benefit analysis. Incorporating developments from these research areas into future modeling and simulation would increase the accuracy and usefulness of analysis regarding the hazards associated with traversing nuclear strike zones.

To prevent waste of taxpayer dollars it is necessary to make informed cost/benefit decisions regarding the hardening of manned and unmanned aerial vehicles in order to ensure safety and survivability. Part of the data needed to inform the cost/benefit analysis is the likelihood of an air vehicle entering a radioactive dust cloud in the event of a nuclear attack. This paper discusses the equations used to calculate the probability of an air vehicle intersecting with a radioactive dust cloud.

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